Standardized Ambulation Assessments Following Spinal Cord Injury

Mary Schmidt Read, Sue Ann Sisto, and John F. Ditunno

During a time of intense interest in neural recovery, there is strong emphasis on quantification of clinical outcomes. To promote responsible outcome measurement, a review of commonly used ambulation assessments was conducted, with an emphasis on application to the population with spinal cord injury (SCI). Each ambulation/walking assessment tool addressed includes a description of the examination, review of statistical support, and information on the utility of the assessment. Ambulation assessment measures are categorized by the variable being measured and considered for use either independently or in combination. In summary, no one assessment quantifies all parameters of ambulation, and comprehensive measurement is completed by using a combination of ambulation/walking assessments to document improvement in walking function after an SCI. **Key words:** *ambulation, ambulatory capacity, gait, gait assessment, locomotion, outcome measures, SCI-FAI, SCIM, walking assessment, WISCI*

One of the most obvious functional skills observed and measured by clinicians is that of locomotion (or ambulation). Persons with incomplete spinal cord injuries (SCIs) ranked this as one of the most important functions for recovery.[1] Outcome measurements of ambulation capacity include various components, such as speed, distance, time, use of assistive devices, amount of physical assistance, physiologic demand, kinematic assessment, and so forth. Each of these may be used singularly or in combination. There is much literature available on each of these parameters and their usefulness and statistical significance in assessing outcomes; however, the publication of the use or validation of these measures in the spinal cord–injured population is limited.[2,3] Quantification of ambulation for both the incomplete and complete SCI populations can be documented by utilizing these measures, however, some may not be appropriate for one or another category. There is a need for more sensitive walking outcome measures for use in SCI clinical practice or research trials to accurately reflect neurologic and functional capacity.[4]

The purposes of this article are to:

- review current walking assessment measures, with an emphasis on those

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commonly used in clinical practice and research trials;
- consider which are appropriate for clinical use with the neurologic presentation of SCI;
- review each relative to pros and cons, utility of the assessment, and statistical support in general and for specific use with SCI.

Before describing the various categories of ambulation assessments, we should consider the underlying impairments that impact functional walking. Various authors[5,6] refer to the correlation of these impairments to the capacity to walk. Consideration should be given as to whether any of these impairments will influence which outcome measure(s) will be chosen. Impairments identified as impacting the capacity to walk include motor strength, sensation, balance, spasticity, proprioception, and cardiorespiratory function.[6] Motor strength has been the impairment most often compared to walking function.[5,7] Other factors could also affect the choice of ambulation assessments, including equipment needs and availability, amount of physical assistance needed and availability, bracing requirements, space requirements, and staff expertise, especially in some of the more complex assessments that require staff training.

When investigating ambulation of persons with SCI, the endpoints or outcome measures used need to be focused on what is anticipated to be a relative level of *improvement* in walking. Patients, clinicians, and researchers consider walking improvement to include the following[8]:
- increased speed
- increased distance
- improved efficiency (cardiovascular or gait parameters)
- better balance
- fewer devices
- less physical assistance

When deciding what assessment to use, we ask whether these parameters can be measured by one test or is a "battery" of ambulation assessments needed to show improvement. How do we define improvement when a combination of factors are interrelated and may produce deviations from a normal progression, such as using a lesser assistive device but then moving at a slower speed or by applying more bracing that results in a lower energy cost?[9]

A review of commonly used ambulation assessments was conducted to present those applicable for use with the SCI population. Each ambulation/walking assessment tool addressed includes a description of the examination, a literature review of statistical support relative to neurologic dysfunction and specific to SCI, plus information concerning the utility of the assessment. When deciding what test to use to measure locomotion, we also need to consider what purpose the information will serve. What data do we want to collect and what is the clinical relevance of these outcome data? How can we use the information gathered in our clinical documentation to support cessation of treatment or continuation during utilization review? How will the tool be used—sequential measurements, pre/post intervention? Should we consider the use of practice runs and a possible training effect? Is fatigue a factor in which measurement is chosen? Will we use measurements singularly or in combination? Has the tool(s) been tested for validity and reliability relative to neurologic dysfunction and specific to SCI? What is the ease of operation and reproducibility by one or multiple assessors? Are we intending to

use a standardized environment or a functional environment during assessment? Are we looking for a functional capacity measure or a disability measure? What resources are needed to implement this tool and what is the cost/benefit ratio of the information collected? Is the use of these measures efficient enough to incorporate into clinical practice? Once these and other questions are addressed, we can proceed with choosing the most appropriate ambulation outcome measure(s) from the categories below or others that are not mentioned in the scope of this review.

In this review, the chosen ambulation assessments are categorized by what parameters are being measured. They are considered for use either independently or in combination and summarized into the following categories: time, distance, speed/velocity, cardiopulmonary capacity, gait analysis, functional capacity, and disability measures.

Measuring Time

This category includes assessments that specify a predetermined fixed distance to walk, with the amount of time to complete this distance being measured, usually with a stopwatch. Once an amount of time is quantified for the distance, subsequent speed/velocity (meters/second) can also be calculated. Various distances have been chosen for this type of assessment, including 3 m, 5 m, 10 m, 50 ft, 50 m, 100 m, 0.5 mile, 2 km, and so forth.[2,10–15]

In other assessment categories, standard distances may be outlined as part of that scale and as characteristic of levels of ambulation success: 10 m is the distance used in the Walking Index for Spinal Cord Injury (WISCI) assessment,[12] the 50 and 150 ft measurements are part of the Functional Independence Measure (FIM)™* assessment,[14] and the Spinal Cord Independence Measure (SCIM) includes a distance of 10–100 m or less than 10 m or more than 100 m.[11]

The unidirectional 10-m walking test (or 10MWT) is the most commonly used ambulation distance measurement either in the clinic or in clinical trials, irrespective of impairment or disability. This test measures short duration walking speed by quantifying the time (in seconds) it takes someone to walk a straight 10 m.[2,10] It may be used as a single measure or, if multiple attempts are used, the average may be calculated for final data collection. This assessment is often used in conjunction with other measures (i.e., speed/velocity, distance/endurance, metabolic analysis, gait analysis, etc.). To perform this simple assessment, a 14-m-long straight course is outlined, using 2 m before and after the measurement area for pre/post warm up/slow down zones. The participant is asked to walk either at a comfortable pace (self-selected) or as fast as they can. Self-selected or comfortable speed has been recognized as the most efficient ambulation in stroke patients and has been recently reported in spinal cord–injured patients.[16–18] Timing starts when the first foot crosses the 2-m line and stops when crossing the 12-m line. Time is quantified in seconds, and speed/velocity can be calculated, if desired. Improvement would be shown with a change of either time or velocity as noted over repeated runs. This measurement alone simply requires one assessor (if participant is independent with or

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without an assistive device), a stopwatch, and a 10-m level straight surface.

Another measurement included in this category is the Timed Up & Go test (or TUG). Although the name refers to a "timed" test, this test is based on use of a specified distance and quantifies the amount of time to stand and complete that distance. It is a modification of the original Get Up & Go test as defined by Mathias[19] for use in looking at balance with the elderly and as modified by Podsiadlo and Richardson[15] to include the addition of a time element. This version (TUG) measures the patient's ability to perform sequential locomotor tasks that incorporate walking and turning. It incorporates the functional elements of sit-to-stand and balance in addition to standard walking. It is considered a quick and easy test to administer, using minimal equipment (chair, stopwatch, 3-m distance) and no special staff expertise. The TUG is performed with a specified 3-m area and the patient's preferred ambulation assistive device. Upon the command "go," the patient moves from sit to stand from a standard armchair, walks to a line 3 m away, turns, walks back to the chair and sits, using a self-selected speed. The test is reported in seconds from "go to sit" and ends with the buttocks touching the seat.

Limited references are found that address the use of the aforementioned time category assessments with the SCI population. Rossier and Wade[10] determined that the 10MWT was a reliable and valid measure of mobility in patients with varied neurologic disorders (including stroke, head injury, tumor, myelopathy, encephalopathy, Huntington's disease, epilepsy, multiple sclerosis, dystrophy, and polyneuropathy), however they did not include any participants with SCI in their study. Various other authors[15,20,21] have also demonstrated good intra- and interrater reliability of the TUG when used with the elderly and persons with either unilateral lower limb amputation or Parkinson's disease (intraclass correlation coefficient [ICC] = 0.99, ICC = 0.93 and 0.96, and ICC = 0.87–0.99, respectively). The TUG has also been shown to have a high correlation with the Berg Balance Scale ($r = –0.81$), walking speed ($r = –0.61$), and the Barthel Index ($r = –0.78$) and content and concurrent validity with the elderly population.[15,22] Van Hedel et al.[2] successfully tested both the 10MWT and the TUG when evaluating ambulation in persons with SCI. He determined that both tests are valid measures for use with persons with SCI and appear to have good intra- and interrater reliability ($r > 0.97$). This same group also showed in another study[23] that timed walking tests were more sensitive and responsive to showing change in ambulatory function for persons at the higher levels of walking capacity than some of the other scales described later in this document (i.e., WISCI).

Van Hedel et al.[18] have reported that the 10MWT represents a sensitive and reliable assessment tool of walking capacity in persons with incomplete SCI. In the same study, they also looked at the use of preferred versus maximum walking speed with the 10MWT and the 6-minute walk test (6MWT) in reference to use with varied functional environments. Preferred walking speed does not always correlate with the potential to participate in the community setting, as evidenced by the need to cross a street in a specified amount of time warranting an increase in voluntary speed. Therefore, it was concluded that both speeds should be considered in a clinical assessment. Use of these timed assessments for measuring results of specific interventions for persons with an SCI are

being documented, as exemplified by Wirz et al.[24] and Hornby et al.[25] in their study of the effectiveness of automated locomotor training in patients with incomplete SCI.

Measuring Distance

This category of ambulation assessments is based on standardizing the amount of time allotted for walking, with the outcome variable being the distance covered within that time. Again, velocity can be calculated, because distance and time parameters are both collected. Brooks[26] stated that "walk tests are quantitative measures of speed and distance that provide information about functional exercise capacity."(p1562) The distance walk test is considered a reflection of endurance and cardiovascular conditioning, although it provides no direct information on cardiopulmonary efficiency. The physiologic costs and subsequent endurance may be dependent upon the choice of varying times, that is, 2-minute, 5-minute, 6-minute, or 12-minute walk tests. The shorter timeframes are more often used for neurological patients who often have less endurance. Cardiac implications would be considered a contraindication or precaution for use of this type of assessment.[27]

The most recognized test in this category is the 6-minute walk test (6MWT). Following the model of the 12-minute walk test, which was originally developed in the 1960s by Cooper,[28] the original guidelines written for the 6MWT were developed for use in cardiac care and were considered an indirect assessment of functional capacity and often exercise capacity.[29] This assessment was accepted as easier to administer, better tolerated, and a better reflection of activities of daily living.[27] This test measures the overall distance traveled on a flat, hard surface in a period of 6 minutes. The results of this assessment are reported as a change in the 6-minute walk distance (or 6MWD). This can either be stated as an absolute value (preferred), as a percentage change, or as a change in percentage of predicted value.[29]

The 6MWT is a practical and inexpensive test and has been shown to have excellent reproducibility.[29] It is easy to administer with no special training and requires minimal equipment (stopwatch, cones for turnaround, tape, a chair, unobstructed hallway, and a lap counter). According to the American Thoracic Society (ATS),[29] this assessment should be done in a standardized environment, preferably an indoor 100-ft hallway with no oval or circular track and no use of treadmill, which would alter the participants' self-pacing. Cones are used for turnaround markers and tape for starting and end lines. A 10-minute rest prior to starting is suggested, and participants should not have exercised vigorously within 2 hours of testing. Participants are asked to walk as far as they can for 6 minutes. They use normal walking aides and a self-selected pace (no running or jogging). Complete, simple instructions are given before the test begins, and the assessor limits verbal dialogue during the 6 minutes to standardized encouragement and time notifications and does not walk along with the participant. This test can be done with or without cardiac or oxygen monitoring equipment. Rests are allowed (in standing position or against a wall) if needed during the 6 minutes; however, if the participant sits to rest, the test is considered complete. At the end of 6 minutes, or whenever the participant stops before that time, the number of laps are counted and total distance calculated. This test has already been used

for persons with SCI in clinical trials, such as the SCILT trial,[30] and a multicenter clinical trial studying the effects of automated locomotor training.[24]

A shorter version of the timed assessments, more commonly used for persons with physical disabilities, is the 2-minute walk test (2MWT). This is run similarly to the 6MWT, however it calculates the distance walked in 2 minutes. It is often used for those populations who would have difficulty walking a full 6 minutes. This test is also considered practical, simple, quick, and easy to administer.[31] Butland et al.[32] showed it to be comparable to the more established 6MWT in persons with respiratory disease. The 2MWT has been used or tested for multiple populations, including amputees, persons with cardiac events, and persons with a variety of neurological diagnoses, including SCI.[2,10,26,31,33,34]

The walk timed tests measuring distance have been assessed by a few investigators for validity, reliability, sensitivity to change, and intercorrelations.[10,26,31,33,34] Their combined work has confirmed construct validity when used with patients with cardiac disease, lower extremity amputations, or neurologic disabilities (not including SCI). They have also cited sensitivity to change ($p < .001$) in persons with cardiac implications and stroke and inter- and intrarater reliability (ICC = 0.90–0.99) within the cardiac, stroke, amputee, and neurologic dysfunction populations. Rossier and Wade[10] showed a significant intercorrelation as valid mobility measures between the 2MWT, the Rivermead Mobility Index (RMI; two versions), and the 10MWT. Van Hedel et al.[2] looked at the use of the 6MWT, along with the TUG and 10MWT, specifically with the SCI population. They reported significant concurrent validity of the three tests ($r > 0.8$); they showed all three to have good correlation with the WISCI II ($r > 0.6$), and intra- and interrater reliabilities were excellent ($r > 0.97$). In another study by van Hedel et al.,[18] the use of preferred versus maximum walking speeds was assessed for persons with incomplete SCI who could perform both the 10MWT and the 6MWT, showing that the 6MWT did not provide additional information about walking capacity compared to the 10MWT. No use to date of the 2MWT specific to the SCI population was found.

One finding noted when examining use of the timed walk tests was the possibility that the distance walked in the defined minutes improved with repeated testings, when clinical practice or the study design called for them.[2,26,35] One possible explanation is that participants experience a training or learning effect. Another suggestion is the potential effect of memory of the previous test and the individual's desire to show improvement. Also, it is possible that there may be a therapeutic treatment effect of the repeated trials. These possibilities should be considered when using the timed tests in clinical practice or trials to determine improvement in walking endurance. It has been suggested that using training walks before testing or use of different corridors or different starting points for repeated testing may help to eliminate this effect.[26]

Measuring Cardiopulmonary Capacity

To measure cardiopulmonary capacity of persons with an SCI during gait, a relative comparison to the individual's maximal exercise capacity is needed. Without this, it would be difficult to determine the demand of activity such as gait on the cardiopulmonary system. This type of measurement is not

usually considered during routine clinical practice but is more often used in clinical trials, due to the resources and training needed to perform this assessment.

For this technique, exercise capacity can be measured using indirect calorimetry that requires wearing of a mask or a mouthpiece to collect expired air. Based on known oxygen and carbon dioxide content and barometric conditions within the ambient conditions, oxygen consumption can be derived. Oxygen consumption reflects aerobic capacity to perform functional activities such as gait. Several portable systems are now available that enable the monitoring of exercise capacity by collecting expired air and analyzing it during gait. These portable metabolic systems are instrumented with telemetry so that the patient is not tethered to a machine.

Aerobic capacity measurement also involves the measurement of heart rate to determine if it is progressing linearly with oxygen consumption. Continuous heart rate can be obtained through the use of a full 12-lead chest electrode arrangement or with a simple heart rate chest strap. The 12-lead chest electrodes represent the electrical signal of the heart contractility electrical pattern. This chest electrode system requires knowledge of normal and abnormal heart rhythms and a trained medical practitioner such as a physician or cardiac nurse to supervise its interpretation. A more sophisticated monitoring of the heart is the most medically safe method of determining heart rate responses to activity such as gait. The fact that this method of assessment is costly and time consuming and requires the services of trained personnel to apply and supervise the test and to interpret the data limits its utilization significantly.

A more clinically efficient method is available when recording with a 12-lead ECG when cardiac safety is not an issue; a simple chest strap can be used to produce a digital recording of heart rate. These chest straps can be synchronized with a customized wristwatch where the heart rates can be viewed for clinical and community-based exercise programs. These wristwatches can be programmed to display the appropriate heart rate range based on age, gender, and body weight, within which an individual with SCI might exercise. Minimal training is needed to utilize such devices. If the intention is to monitor and review heart rate over a long period of time, heart rate monitor chest straps can be purchased with software that enables the heart rate profiles to be downloaded to a personal computer. Heart rate monitoring must always be evaluated in terms of the degree to which the autonomic nervous system is intact.[36] Generally speaking, those individuals with a SCI at T6 and higher will have abnormal cardiac regulation of the heart. In these cases, ratings of perceived exertion (RPE) could be used as a measure of effort.[37]

Once a person's maximal aerobic capacity is determined, the submaximal aerobic capacity can be compared to the individual's maximal capacity. These tests are usually performed on a wheelchair treadmill or roller system or by using an upper body ergometer, referred to as arm crank ergometry (ACE). If patients are ambulatory, these tests are more appropriately performed during treadmill walking so interpretations can be made based on task specificity. In other words, if ambulatory aerobic capacity is being explored, then the test should be performed while the patient performs that task. Although treadmill walking has been established to be different

from overground ambulation, it provides a standardized manner with which to perform a progressive protocol, and it is easily replicated for postintervention follow-up testing. Treadmills and upper body ergometers are usually available as part of a comprehensive SCI rehabilitation program.

An alternate form of measuring exercise capacity through expired air or oxygen consumption determines how much work a person can generate over a given period of time, defined as power. Dallmeijer et al.[38] studied the effect of wheelchair propulsion capacity of 132 persons with SCI before and after rehabilitation; 37 of those studied had tetraplegia. Exercise capacity was measured as the maximal power output that could be generated on a wheelchair treadmill during a maximal exercise test. Power output increased by nearly 14 watts, but persons with tetraplegia, complete injuries, women, and older persons had less improvement in power output. This technique again requires the use of more specialized equipment and training.

There are numerous other examples of arm ergometer tests for determining exercise capacity, however there are fewer examples of treadmill tests for ambulatory patients with SCI. Ideally, the protocol should be based on the person's body weight, and the load at each stage can be quantified in terms of metabolic equivalents (METs) with a 1-MET increment per stage.[39] Treadmill exercise protocols for SCI should follow the same standardized protocols as those used for able-bodied individuals (ACSM guidelines[40]), however weakness may pose biomechanical limitations to a progressive treadmill protocol. In most cases of incomplete SCI where individuals are ambulatory, the muscle weakness is in the distal segments. In these cases, it may be advisable to measure maximal and submaximal aerobic capacity with an orthosis. This orthotic support should be replicated for any later tests if comparisons of change in aerobic capacity are to be made, because the orthotic support will make the effort of walking easier. Due to this muscle weakness, it is also possible to progress the treadmill protocol with inclines rather than speed. Increasing the load through incline testing enables the speed to be maintained at a level that can be sustained considering the muscle weakness. An overhead safety harness may also be used to protect the individual in the event of stumbling during the treadmill test, especially when the workloads become difficult. Caution should be used in evaluating the aerobic capacity with an overhead harness as the harness may reduce the aerobic demand in a variable manner that may not be replicable for subsequent tests. Similarly, avoidance of holding onto treadmill handrails is necessary, as the amount of support through the upper limbs reduces the aerobic demand in a variable and immeasurable manner.

Stewart et al.[37] describes the measurement properties of fitness assessments of persons with SCI between admission and discharge from a rehabilitation center and an 8-week follow-up. Exercise testing was performed using a wheelchair or arm crank ergometer. The authors reported the measures at higher levels of physical exertion showing higher stability between test and retest (ICC = 0.79–0.82). Resting measures, blood lactates, and respiratory exchange ratios were not stable (ICC = 0.35 and 0.37, respectively). The authors also indicated that heart rate, blood pressure, lactate levels, ventilation rates, and activities of daily living measures did not reflect the aerobic fitness and that the use of

ratings of perceived exertion to predict heart rate was inaccurate in the SCI population.

Ulkar et al.[41] studied the energy expenditure of walking with a walker versus crutches in nine patients with SCI (levels C6 to L2) compared to able-bodied individuals. They showed a statistically significant difference between controls and persons with an SCI in terms of walking velocity and oxygen cost. The patients with SCI walked significantly more slowly and less efficiently. Velocity was higher and oxygen cost was lower for those crutch walking. The authors concluded that energy expenditure studies are useful tools for obtaining objective measures to determine utility of various assistive devices during daily activities. Consideration must be given to the relative cost of equipment for this type of assessment as well as to the staff training for competent data collection. This assessment might also be used in combination with another category, such as a timed or distance measurement.

Measuring by Gait Analysis

Assessment of the quality of an individual's gait cycle usually includes some form of gait analysis, either in a quantitative or observational mode. This assessment can also offer information relative to the mechanical efficiency of gait. Information from a gait laboratory allows for a comprehensive evaluation that can supplement observational gait analysis.

Quantitative gait analysis through sophisticated instrumentation is an effective method to evaluate three-dimensional kinematics (joint range of motion) and kinetics (forces). Through computerized machinery, objective measurements of moments and forces can be collected for comparison of change at periodic assessments of participants with SCI following interventions. Specific moments can be calculated to determine the forces acting upon muscles, ligaments, and tendons. Isolated external and internal forces, such as ground reaction forces, gravity, joint, muscle, and ligamentous forces, plus inertial forces of the limb segments can be calculated. Force plates embedded in the walkway or treadmill capture the ground reaction forces and moments during the gait cycle. Additionally, muscle activity is captured by either surface electrodes or fine wires inserted into the muscles of the legs. Quantitative gait analysis, through the use of dynamic electromyography (EMG), can be particularly useful in detecting abnormal muscle firing patterns (spasticity) and may guide chemodenervation interventions. The heel or full sole can be instrumented with a switch to indicate when each foot hits and leaves the ground, when processing the temporal (velocity, cadence, step and stride time) and spatial (step and stride length) components of gait. Through the use of expensive computer hardware and software, all the data are synchronized and normalized in time according to the gait cycle. Clinical and computer expertise are necessary components to the integrity of the use of this type of assessment, usually requiring specific training. Again, this is not a form that is readily found in the clinical environment.

In addition, assessment of normal gait kinematics includes the review of phases and planes of motion during the gait cycle. Phases of motion include all the elements of the stance and swing phases. Joint movements throughout the gait cycle occur in the various planes of motion, including the sagittal, coronal, and transverse planes. For comprehensive gait analysis, it is optimal to be

able to capture information from all of these components. Quantitative kinematic measurements are most commonly captured via a series of cameras surrounding a walkway or treadmill. These cameras are designed to detect sensors placed on the body that define body segments and joints. The sensors can be active light emitting diodes (LEDs) or passive retro-reflective markers. Quantitative gait analysis does not require the observer to position him/herself adequately to be able to view all these planes and phases, rather the cameras capture full motion in three dimensions. Again, video gait analysis, like kinetic gait analysis, requires a costly system of computerized machinery and a level of expertise and training for utilization and analysis.

It is universally recognized that extensive kinetic or video gait analysis systems have limited availability in the clinical environment, therefore less resource intensive means of quantifying temporo-spatial gait parameters are desirable. This type of objective clinical assessment could be helpful in early identification of potential fallers, documentation of illness-specific gait disorders, and identification of intervention-related changes in rehabilitative therapies. One alternative presently available and being used in research and clinical environments is an electronic pressure-sensitive walkway mat. The GAITRite® Walkway System by CIR Systems, Inc. (Clifton, NJ) is one such commercially available device. This instrumented "carpet" walkway system consists of a portable computerized pressure-sensitive mat (approx 3-ft wide and of varying lengths starting at 14 ft) integrated with a laptop computer containing GAITRite software. Pressure sensors are embedded in the walkway that detect footfalls as the person walks across the length of the mat. The software is able to record temporal and spatial gait parameters, including walking speed, cadence, step length, single and double limb support, stride width, and foot placement angles. The walkway is placed in an area to allow the person to begin walking a few meters prior to the starting edge of the mat and decelerate once off the mat. Ambulation is usually at a self-selected pace utilizing normal assistive devices. Markings from the assistive devices can be eliminated by the software during analysis.

A number of studies[42–45] have compared results of the use of GAITRite assessments with other gait measures (such as chalk footsteps, powdered footprints, in-shoe pressure measurement tools, and video movement analysis systems) and reported variable results, but all supported the use of the GAITRite as a valid tool for objective gait analysis. A high level of intertrial repeatability by the GAITRite for the measurement of spatiotemporal variables is reported by Bilney et al.[43] Greater consistency of these gait parameters is demonstrated at preferred or faster walking speeds than at slow speeds, although all speeds show high ICC values. Following initial training, use of the GAITRite system is considered a quick and simple objective measure of selected spatial and temporal gait parameters useful in a clinical setting. No studies supporting use of the GAITRite specifically with persons with SCI were found.

Quantitative gait analysis has been readily accepted as an important and needed assessment tool for surgical and rehabilitative planning. Computerized gait analysis measures gait parameters more precisely than is possible with clinical observation alone and is widely used in the evaluation and treatment planning for patients with gait

abnormalities.[46,47] It has been shown that surgical decision making is altered in 52%–92% of children who undergo gait analysis.[48] Although gait analysis in children has been widely used, only one study described gait analysis with children and adolescents with SCIs.[49] The goal of this study was to demonstrate the utility of instrumental gait analysis in children and adolescents with SCIs. Quantitative gait evaluations and physical examinations were performed on 33 children and adolescents with SCIs. The authors reported abnormal kinematic patterns that were repeatable over several years and concluded that gait analysis was beneficial in making educated treatment decisions about orthotic prescription, surgery, postsurgical evaluation, prescription of new therapy, evaluation of spasticity medications, and experimental treatments. The authors also concluded that treatments such as physical therapy, orthotics, spasticity management, and surgery as well as innovative new areas such as functional electrical stimulation and robotic-assisted therapy rely on quantitative gait analysis to provide a baseline of walking patterns from which to measure functional improvements.

In contrast, observational gait analysis includes the visual inspection of walking by a trained clinician who reviews particular elements of the gait cycle as performed by the patient. One particular observational gait assessment instrument designed specifically for use with SCI is the Spinal Cord Injury Functional Ambulation Inventory (SCI-FAI; **Table 1**).[50] Although there are many observational gait analysis instruments available in the literature, the SCI-FAI incorporates elements specific to the clinical presentation expected following an SCI. It was designed to be used both clinically and in research. This observational gait assessment instrument addresses three domains of performance: gait parameters/symmetry, assistive device use, and temporal-distance measures. The gait parameters/symmetry component includes six ranked gait components that describe some elements of quality of movement and are weighted in scoring based on clinician-determined relative importance of the gait parameters. The second domain describes use of assistive devices and differentiates upper extremity balance/weight bearing devices from lower extremity orthotics, with the weighted scoring dependent upon the degree of assistance provided by each. Walking speed and distance are assessed by use of a self-perceived walking mobility scale, as modified from the Functional Walking Category scale published by Perry et al.[51] A 2-minute walk test (2MWT) was included as a measure of walking speed and endurance. The reliability and validity of this assessment has been addressed only by the scale developers, Field-Fote et al.,[50] showing both inter- and intrarater reliability (ICC = 0.703–0.960) for the objective and observational domains. They also demonstrated validity by correlations between the gait score and walking speed (r = 0.700). Moderate sensitivity was also shown as a percentage change in gait score (44.7%) following rehabilitation intervention, and moderate correlations were noted between change in gait score and lower extremity motor scores (LEMS; r = 0.58). This standardized assessment for clinical use is quick and easy to perform, requiring only one assessor, time clock, minimal space, and standard assistive devices for upper and lower extremities. It was found equally reliable whether the observation is performed live or from videotaped records.

Table 1. SCI Functional Ambulation Inventory (SCI-FAI)

SCI Functional Ambulation Inventory (SCI-FAI)

Name: Session: Date:

PARAMETER	CRITERION	L	R	
A. Weight shift	shifts weight to stance limb	1	1	
	weight shift absent or only onto assistive device	0	0	
B. Step width	swing foot clears stance foot on limb advancement	1	1	
	stance foot obstructs swing foot on limb advancement	0	0	
	final foot placement does not obstruct swing limb	1	1	
	final foot placement obstructs swing limb	0	0	
C. Step rhythm (relative time needed to advance swing limb)	at heel strike of stance limb, the swing limb:			
	begins to advance in <1 second *or*	2	2	
	requires 1–3 seconds to begin advancing *or*	1	1	
	requires >3 seconds to begin advancing	0	0	
D. Step height	toe clears floor throughout swing phase *or*	2	2	
	toe drags at initiation of swing phase only *or*	1	1	
	toe drags throughout swing phase	0	0	
E. Foot contact	heel contacts floor before forefoot *or*	1	1	
	forefoot or foot flat first contact with floor	0	0	
F. Step length	swing heel placed forward of stance toe *or*	2	2	
	swing toe placed forward of stance toe *or*	1	1	
	swing toe placed rearward of stance toe	0	0	
	Parameter total			Sum /20

ASSISTIVE DEVICES		L	R	
Upper extremity balance/weightbearing devices	None	4	4	
	Cane(s)	3	3	
	Quad cane(s), Crutch(es) (forearm/axillary)	2	2	
	Walker	2		
	Parallel bars	0		
Lower extremity assistive devices	None	3	3	
	AFO	2	2	
	KAFO	1	1	
	RGO	0	0	
	Assistive device total			Sum /14

TEMPORAL/DISTANCE MEASURES				
Walking mobility (typical walking practice as opposed to W/C use)	Walks ...			
	regularly in community (rarely/never use W/C)	5		
	regularly in home/occasionally in community	4		
	occasionally in home/rarely in community	3		
	rarely in home/never in community	2		
	for exercise only	1		
	does not walk	0		
	Walking mobility score			Sum /5
Two-minute walk test (distance walked in 2 minutes)	Distance walked in 2 minutes = ...		feet/minute	meters/minute

AFO: ankle-foot orthosis; KAFO: knee-ankle-foot orthosis.

Reprinted from Field-Fote EC, et al. The spinal cord injury functional ambulation inventory (SCI-FAI). *J Rehabil Med.* 2001;33(4):177–181.

Measuring Functional Capacity

Functional capacity assessments, as defined by the World Health Organization (WHO),[52] measure functions that support the performance of self-care and mobility in the environment but are assessed in a standardized environment.[4,8] This type of measure may be viewed as a bridge between impairment measures and disability scales.[4] Included in this category is the primary walking capacity scale presently being utilized on persons with SCI, the WISCI II.[30,53] WISCI II, or Walking Index for Spinal Cord Injury, Version 2, [12] is a walking capacity/functional assessment that was developed by an international team specifically for use in SCI clinical trials, however some are beginning to use it to quantify ambulation of persons with SCI in the clinical setting. This scale includes components of distance, physical assistance, lower extremity bracing, and ambulatory aides, so it therefore also includes features of a disability scale as defined by the WHO.[52] The WISCI scale was revised in 2001[54] to include a zero level and further describe bracing, as advised by users. It was never developed to reflect quality of gait, sit to stand function, walking speed, or energy consumption, however, some investigators have chosen to include a time element with the scale.

WISCI II (**Table 2**)[54] presents as a 21-level hierarchical scale, ranking from the most impaired (Level 0) to the least impaired (Level 20). The WISCI level ranking was based on impairment improvement rather than just independent function and is intended to focus on capacity not disability or burden of care.[4,12] A descriptor grid offers the opportunity to quantify types of ambulation aides, bracing variations, and patient comfort level, so that changes can be documented over time. Improvement in walking is based on the change of scores from sequential examinations. Use of WISCI II is easily reproducible and practical, as equipment needs are standard alternative lower extremity bracing options and ambulation aides that are available in most clinics. Besides scoring by direct observation, photo documentation has been shown to be a reliable method of assigning WISCI levels, with a high interrater reliability (96% agreement) reported.[55] This test also utilizes the standardized distance of a unidirectional 10 m (if within parallel bars a turn is necessary to complete 10 m), a comfortable, self-selected walking pace, and a reciprocal gait. One assessor guards the participant throughout the 10-m walk and assigns what is considered the safe WISCI II level based on the parameters observed. To qualify in a level, that level must be completed as defined. Dependent upon the clinical protocol, some clinicians or investigators may decide to allow the participant to choose the pace and assistive device to test with, and some may choose to challenge the participant to higher WISCI levels or to drop the participant to lower levels if he or she cannot complete a 10-m distance on any given level. It should be noted that WISCI II was meant to be used with the levels as defined and not to equate existing patient ambulation modes (that do not match any of the 21 levels) with one of the defined levels on the scale. However, as a supplement to current clinical practice, adjudication procedures are under consideration by the developers for use with clinical presentations not matching defined WISCI levels. Given that environmental factors may vary the requirements for ambulation (i.e., use of assistive devices or braces while ambulating

Table 2. Walking Index for Spinal Cord Injury, Version II

Name_____ Date_____

Check descriptors that apply to current walking performance, then assign the highest level of walking performance. (In scoring a level, one should choose the level at which the patient is safe as judged by the therapist. If devices other than stated in the standard definitions are used, they should be documented as descriptors. If there is a discrepancy between two observers, the higher level should be chosen.)

Descriptors: (circle or check)

Gait: reciprocal _____; swing through _____

Devices	**Braces**	**Assistance**
//bars < 10 meters	Long Leg Braces—Uses 2___ Uses 1___	Max Assist x 2 people
//bars 10 meters	Short Leg Braces—Uses 2___ Uses 1___	Min/Mod assist x 2 people
Walker—	Locked at knee ____	Min/mod assist x 1 person
Standard	Unlocked at knee ____	
Rolling		
Platform		
Crutches—	Other: _____	
Uses 2		
Uses 1		
Canes—Quad		
Uses 2		
Uses 1		
No devices	No braces	No assistance

WISCI Levels

Level	**Devices**	**Braces**	**Assistance**	**Distance**
0				Unable
1	Parallel bars	Braces	2 persons	Less than 10 meters
2	Parallel bars	Braces	2 persons	10 meters
3	Parallel bars	Braces	1 person	10 meters
4	Parallel bars	No braces	1 person	10 meters
5	Parallel bars	Braces	No assistance	10 meters
6	Walker	Braces	1 person	10 meters
7	Two crutches	Braces	1 person	10 meters
8	Walker	No braces	1 person	10 meters
9	Walker	Braces	No assistance	10 meters
10	One cane/crutch	Braces	1 person	10 meters
11	Two crutches	No braces	1 person	10 meters
12	Two crutches	Braces	No assistance	10 meters
13	Walker	No braces	No assistance	10 meters
14	One cane/crutch	No braces	1 person	10 meters
15	One cane/crutch	Braces	No assistance	10 meters
16	Two crutches	No braces	No assistance	10 meters
17	No devices	No braces	1 person	10 meters
18	No devices	Braces	No assistance	10 meters
19	One cane/crutch	No braces	No assistance	10 meters
20	No devices	No braces	No assistance	10 meters

Level assigned_____ Revised 3/19/2002

Reprinted from Ditunno PL. Walking Index for Spinal Cord Injury (WISCI II): scale revision. *Spinal Cord.* 2001;39:654–656.

outdoors that are not needed if ambulating indoors), it is recognized that different WISCI levels may be scored for different forms of ambulation by the same person.[56] It has also been reported that many people with chronic SCI are capable of ambulating at different WISCI levels dependent upon whether they are given the choice to use a self-selected level of function or encouraged to ambulate at maximum capacity on the WISCI scale.[56] Self-selected WISCI levels have been shown to be more efficient, as evidenced by greater velocity and decreased physiological cost index and total heart beat index.[56]

WISCI II has been shown to be a valid (construct, prospective, concurrent, criterion, predictive, and face) and reliable measurement, either in an observational mode or by use of photo documentation.[12,53,55,57–60] Morganti et al.[53] demonstrated that, although WISCI II correlated well ($p < .001$) with the Rivermead Mobility Index (RMI; $r = 0.67$), Barthel Index (BI; $r = 0.67$), FIM™ ($r = 0.7$), and SCIM ($r = 0.97$), the WISCI II scale is more sensitive to incremental change than each of the other four assessments. They also showed more patient distribution by WISCI levels (12) when the same patients were categorized by the four other scales (four in FIM™, three in the BI, two in RMI, and five in SCIM). Also supporting sensitivity of the instrument, in a preliminary report on acute SCI patients, Ditunno et al.[4,59] reported that seven different WISCI levels (12–13, 15–17, and 19–20) were recorded on patients who were scored with the same FIM™ level of 5 (supervision), suggesting again more discrimination from use of the WISCI scale than the FIM™ locomotor subscale. However, in a multicenter clinical trial by Wirz et al.[24] on automated locomotor training, the WISCI II was less sensitive to changes, as the 10MWT, the 6MWT, and the TUG tests were all able to show changes in specific components of gait. In a study by van Hedel et al.,[2] it was shown that overall the WISCI II correlated well with the 10MWT, 6MWT, and the TUG ($r > 0.60$). However, in SCI persons with severely impaired walking ability, the WISCI II correlated poorly with these timed tests. In another study by the same investigators[23] looking at responsiveness of certain walking tests over a year of time post incomplete SCI, the WISCI II displayed a ceiling effect compared to the 6MWT and 10MWT, which showed a continued responsiveness to change over time. Various authors[3,18,23,53,61] support the opinion of the ICCP (International Campaign for Cures of Spinal Cord Injury Paralysis) Clinical Guidelines Panel that a more accurate assessment may be provided by a combination of the WISCI scale and other quantitative timed walking tests (i.e., 10MWT, 6MWT). This suggestion supports the continued use of a popular combination of walking assessments we see in clinical trials (WISCI, 10MWT, and 6MWT) altogether quantifying gait parameters, assistance, use of devices, distance, and speed. WISCI II and the 10MWT can be performed simultaneously to enhance efficiency.

WISCI II study results have also shown a monotonic progression of levels correlating highly with lower extremity motor score improvement ($p < .001$), changes in walking speed ($p < .0001$), and changes in FIM™ and SCIM scoring.[53,58–60,62] In the SCILT trial,[30] the results showed the responsiveness of the WISCI scale to improvement in neurological recovery reflected in the LEMS and correlated with other primary and secondary outcome measures such as walking speed, distance measure, locomotor FIM™, and

Berg Balance Scale.[57,58,60] Additional work is needed to show whether the WISCI scale can measure how well participants walk in regard to speed, distance, and energy requirements.[56,63]

Measuring Disability

Differentiating from the functional capacity tests addressed previously, disability assessments measure self-care and mobility in different physical environments such as the hospital, home, outdoors, cities, and rural areas.[8] These disability measures may or may not be standardized and attempt to show how the outcome correlates to function within their environment, whether it be home, work, and/or community. Included in this category are quantifiable ambulation activity monitoring and observation activity assessments. The observation assessments may be either clinician observed or patient reported and most often use physical function scales developed specifically for the measurement tool. These scales usually quantify level surface ambulation and elevations separately.

The Step Activity Monitor (SAM; Cyma Corporation, Seattle, WA) is a simple device used to quantify ambulatory activity (rather than disability) by counting steps. It is a small (size of a pager), lightweight, sealed, microprocessor-driven accelerometer worn on the ankle, which can capture walking performance throughout all environments over long periods of time. It does not interfere with the gait cycle, while it continuously records the number of steps per time interval over extended periods. The SAM reports only the steps taken by the leg on which the device is placed; it does not reflect a bilateral stepping total. Programming (either standard or individualized) capabilities of the device allow it to count steps during predetermined time spans, allowing step detection at various points in the day and not just total activity. Training is necessary for the programming of a few questions describing the person and their gait, however application of the device and data downloading to the respective computer software are quick and simple. Reports can be generated showing the number of steps/minute over time. Bowden and Behrman[64] analyzed the accuracy and test-retest reliability with use of the SAM with persons with incomplete SCI and found it to be an accurate and reliable device for capturing walking activity in this population. The SAM was 97% accurate compared with hand-tallied step counts when evaluated during laboratory-based standardized timed tests (6MWT and 10MWT), when ICC values for test-retest reliability of the 10MWT and 6MWT were 0.97 and 0.99, respectively. Shaughnessy et al.[65] have also shown in the stroke population that the SAM is more sensitive to changes in ambulation activity than gait speed, endurance, or the FIM™. Resnick et al.[66] reported high ICC of $r = 0.84$, reflecting reliability with use of the SAM with older adults. McDonald et al.[67] supported the use of the SAM in children, citing the advantage of increased compliance with this population over other measures of activity. In two different studies, Shepherd[68] and Silva[69] reported that SAM had less error when reporting all activities than the use of a pedometer. It is felt that the use of a SAM across environments and time may measure more meaningful ambulatory behavior as a participation measurement of function.[64]

Specific examples of some clinician-observed disability measurements used for persons with SCI include the FIM™, the Barthel, and the SCIM. The FIM™[14] is an

assessment of overall physical functioning known to measure the burden of care for a person with any physical disability or how much assistance the person with a disability requires for daily functions. All activities listed are measured on a 1- to 7-point scale, relative to the amount of assistance required to complete the specified function. It is not considered a measure of enhanced performance or improvement of impairments but an indicator of severity of disability, with the scale designating major gradations in behavior from dependent (1) to independent (7). Specific to the FIM™ locomotor subscale, it was not developed to relate a change in levels of walking. The descriptive levels of walking only indicate the amount of assistance needed, based on a distance of less than 50 ft (15 m) or greater than 150 ft (50 m). There is often confusion by raters on how to properly score the walk versus wheelchair functions. Staff of most rehabilitation facilities in the United States presently use the FIM™, as it has been adopted by the US government for use in the tool that determines reimbursement for rehabilitation care, including for persons with SCIs. The FIM™ is considered simple to use following training and, as a global instrument, has tested as valid and reliable and requires minimal resources. The subscale for walking has not been validated independent of the global scale,[4] although it has been used in SCI clinical trials, such as the SCILT project.[30]

The Barthel Index[70] and the Modified Barthel Index are older observational functional assessments that have been routinely replaced by the FIM™ and are also not validated specific to the SCI population. The Barthel Index includes an item addressing walking on a level surface. The two possible scores for ambulation imply the patient is capable of walking 50 yards, either with minimal help or without assistance. If the patient is unable to walk 50 yards, they are scored for use of a wheelchair. This assessment of locomotion is limited and not very sensitive to change, although the measure has shown validity and interrater reliability. Use of the Barthel Index in SCI clinical trials is usually in comparison with other functional scales.[71]

The SCIM is the newest observational assessment of overall physical functioning specific to persons with a spinal cord lesion; it was developed in 1997,[11] revised as SCIM II in 2001,[72] and reported as SCIM III in 2006.[73] The SCIM was developed with the intent of being more sensitive for persons with SCI than the more global functional disability measures (FIM™, Barthel Index) and scored according to the item's proportional weight in the patients' general activity. The main difference between the SCIM and the FIM™ is the relative weight given to the different tasks, especially those related to sphincter control and mobility.[11] The SCIM includes items listed in three categories: self-care, respiratory and sphincter management, and mobility. For the mobility categories, the descriptors include reference to assistive devices, lower extremity bracing, type of gait (swing vs. reciprocal), amount of physical assistance, and three distances (either indoors <10 m, between 10 and 100 m, or >100 m). The mobility items are grouped according to these distance parameters, with the same descriptors listed under each distance section. As noted by Ditunno[4] and Catz,[74] the walking subsale of the SCIM contains less descriptive walking levels than the WISCI.

To complete the SCIM assessment, the assessor (either multidisciplinary or singular assessor) observes performance and scores according to the defined descriptive levels.

Table 3. Summary of cited assessments

Assessment	Use with diagnoses other than SCI	SCI use	SCI validity references	SCI reliability references
10 MWT	Amputee, CV event, cardiac, arthritis, HI, MS, transplant, encephalitis	Acute & chronic	van Hedel[2]	van Hedel[2] van Hedel[18]
TUG	Vestibular, amputee, CV event, elderly, Parkinson's	Acute & chronic	van Hedel[2]	van Hedel[2]
6 MWT	Cardiac, pulmonary, elderly, CV event	Acute & chronic	van Hedel[2]	van Hedel[2]
2 MWT	CV event, HI, cardiac, MS, amputee, pulmonary, encephalitis	Acute & chronic	*	*
Cardiopulmonary capacity	Any disability	Chronic	*	*
Quantitative gait analysis	Any disability	Acute & chronic	*	*
SCI-FAI	Not applicable	Acute & chronic	Field-Fote[50]	Field-Fote[50]
WISCI	Not applicable	Acute & chronic	Ditunno[12,54,55,57–60] van Hedel[2] Morganti[53] Kim[56]	Ditunno[12,55] Morganti[53]
SAM	CV event, orthopedics, geriatrics, pediatrics	Subacute & chronic	Bowden[64]	Bowden[64]
FIM™	Any disability	Acute & chronic	*	*
Barthel	Any disability	Acute & chronic	*	*
SCIM	Not applicable	Acute & chronic	Catz[11,72,73]	Catz[11,72,73]
Ambulatory capacity categories	CV event	Chronic	*	*

Note: 10MWT = 10-m walking test; CV = cerebrovascular; HI = head injury; MS = multiple sclerosis; TUG = Timed Up & Go; 6MWT = 6-minute walk test; 2MWT = 2-minute walking test; SCI-FAI = Spinal Cord Injury Functional Ambulation Inventory; WISCI = Walking Index for Spinal Cord Injury; SAM = Step Activity Monitor.
*No references cited for SCI specific validity and/or reliability.

The total SCIM score is recorded upon completion and ranges between 0 and 100. Longitudinal improvements can be monitored by periodic assessments of function with this assessment tool. As the SCIM is an observational or interview assessment of daily functional tasks, it requires no special equipment or space and only an understanding by the assessor of the items identified.

As a global instrument, the SCIM has been repeatedly reported to be more precise, descriptive of ambulation, and sensitive to change in function than the FIM™ and the Barthel Index.[11,72,74] Catz et al.[11] reported content, face, and construct validity compared to FIM™ in the early version of the total SCIM; however, as with the FIM™, the walking subscale has not been individually validated.[4] SCIM was shown to be more sensitive than FIM™ for each subgrouping of paraplegia, tetraplegia, complete, and incomplete lesions, as the FIM™ missed

25%–27% of the functional changes detected by the SCIM.[74] Reliability of the SCIM I and II has been tested by both observation and interview methods.[75] Results supported the reliability of the SCIM assessment by interview and showed it to be comparable with assessment by observation (r = 0.69–0.96, $p < .001$). An international, multicultural study[73] utilized a Rasch analysis that established cross-cultural validity, reliability, and usefulness of SCIM III across six countries from North America, Europe, and the Middle East. Unfortunately, it did not include any sites from the United States. An attempt is in process to duplicate the SCIM III study in the United States to establish local cultural significance. It is hoped that the SCIM can serve as a universal tool for future disability assessment of spinal cord lesion patients, both in clinical and research assessment.[74]

In the patient reported portion of this category of ambulation assessment tools, patient reported questionnaires or PROs (patient reported outcomes) are used, where patients subjectively report information on their perceived levels of exertion, distance, use of stairs, and so on, in reference to their ambulation capacity. These measurements may also be a subgroup of quality of life questionnaires that ask the participants not only what they are capable of doing but also what they are satisfied with and/or what is important to them. Whatever it includes, often disability measurement questions are asked pre and post intervention and are correlated with other objective locomotion data. For example, the classification system known as the functional walking categories, although developed for persons with stroke,[51] has been used in spinal cord–injured patients as the Ambulatory Capacity Categories by Kim et al.[7] and modified into the Walking Mobility Scale for the SCI-FAI by Field-Fote.[50] This categorization is based on a therapist's assessment of the participants' walking level along with the participants' description of their walking capacity as practiced in the home and community environments. Other quality of life assessments that include questions relative to ambulatory capacity are descriptive in nature and offer only subjective outcome measures of functional improvement. The only burden to administering this type of measurement is if the patient needs assistance writing answers to questionnaires due to lack of hand function or reading abilities.

Discussion

Table 3 displays the current use, application, and SCI-specific statistical support of the ambulation assessments cited within the scope of this review. At the time of this review, the literature shows SCI population-specific validation only with the following ambulation assessments:

- TUG, 10MWT, 6MWT, plus good correlation with WISCI[2]
- SCI-FAI[50]
- WISCI[12,30,53]
- SAM[64]
- SCIM[11,72,74,75]

Conclusion

Change in walking capacity is a popular and desirable outcome for the person with an SCI. Clinical practice and clinical trials will continue to address it using various interventions. Some commonly used ambulation assessment tools have been reviewed that can be used in both clinical practice and clinical trials with the SCI population. Each has been described, statistically addressed, and utility discussed. As can be seen from **Table 3**

portraying use of walking assessments with the SCI population, more work is needed to validate the use of other ambulation outcome measures specific to the SCI population or to maximize combinations of assessments if they are to be used in future institutional and multicenter clinical practice and/or clinical trials.

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